Issued August 8, 1912.

U. S. DEPARTMENT OF AGRICULTURE,

OFFICE OF PUBLIC ROADS—BULLETIN NO. 46.

LOGAN WALLER PAGE, Director.

OIL-MIXED PORTLAND CEMENT CONCRETE.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Public Roads,
Washington, D. C., March 9, 1912.

Sir: I have the honor to transmit herewith the manuscript of a bulletin entitled "Oil-Mixed Portland Cement Concrete," which I have prepared. Ordinary Portland cement concrete, because of its absorptive qualities, is used in some structures with only partial success. When made proof against the permeation of moisture, not only is its field of usefulness rendered more universal, but its efficiency is likewise greatly increased. This bulletin explains a very simple method for damp-proofing concrete by the incorporation of mineral oil residuum with the ordinary concrete mixture. It also describes the application of oil-mixed Portland cement concrete to several much-used types of structures in which a damp-proofed building material would be of benefit. I therefore request that this document be issued as Bulletin 46 of this office.

Respectfully,

L. W. Page,
Director.

Hon. James Wilson,
Secretary of Agriculture.

ILLUSTRATIONS.

PLATES.

FIGURES.

OIL-MIXED PORTLAND CEMENT CONCRETE.

INTRODUCTION.

The enormous growth of the American Portland cement industry, with its production of 76,549,951 barrels of cement in 1910 and 78,528,637[1] barrels in 1911, is striking evidence of the widespread use of this deservedly popular material of construction. Combined with sand and stone or gravel in the correct proportions and mixed with the proper amount of water, the resultant product—concrete—is a structural material of perhaps more universal adaptation than any other material now in use. Its application to foundations for heavy machinery, to dams, walls, bridge piers, tunnels, subways, and building blocks is well known. When properly reinforced with steel, its use is even more widely extended to the construction of bridges, vats, sewers, water conduits, and numerous other classes of construction.

The farmer has found concrete to be of material benefit to him in building various farm structures which were formerly made of more perishable materials. Thus, when reinforced with steel wire or rods, fence posts may be made with an interminable life and at very low cost. It is also exceedingly well adapted to the construction of water tanks, cisterns, silos, pavements, floors, buildings, feeding troughs, etc. Simplicity and ease of manufacture and manipulation in construction, great strength and durability, and comparatively low cost are some of the considerations which render its application so universal.

In spite, however, of the many virtues possessed by concrete as a material of construction, faults are apparent in its tendency to crack, owing to external temperature changes, to the rise and subsequent fall of temperature while it is hardening, and to the shrinkage which accompanies the drying out of the mass. Then, too, as ordinarily made, concrete is more or less porous and absorbent of moisture—characteristics of the material which are plainly evident in the damp appearance of concrete houses after a period of wet weather, in leaky basement walls and floors, and in reservoirs which persist in losing water.

If concrete could be made less absorbent of moisture and less porous, its ability to withstand the penetration of water would be greatly increased, and the material would then be a much more desirable one for constructions in which it is now used with only partial success.

[1] Figures supplied by U. S. Geological Survey.

OIL-MIXED CONCRETE.

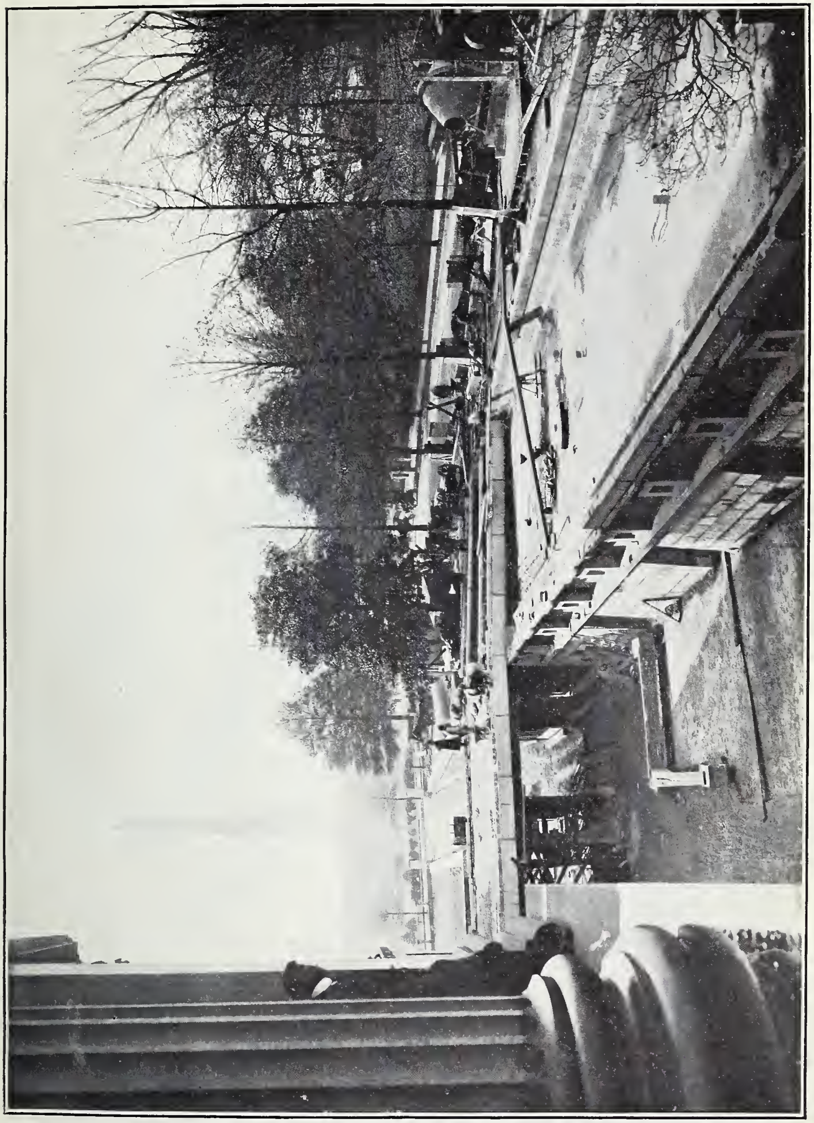
While experimenting in the Office of Public Roads in an attempt to develop a nonabsorbent, resilient, and dustless road material, one capable of withstanding the severe shearing and raveling action of automobile traffic, the writer's investigations led him into a very promising discovery. He found that, when a heavy mineral residual oil was mixed with Portland cement paste, it entirely disappeared in the mixture, and, furthermore, did not separate from the other ingredients after the cement had become hard. The possibilities of oil-cement mixtures for waterproofing purposes were recognized and extensive laboratory tests were immediately begun to determine the physical properties of concrete and mortar containing various quantities of oil admixtures.

LABORATORY INVESTIGATIONS.

Many valuable data have been obtained from these investigations. The damp-proofing properties of concrete mixtures containing oil have been demonstrated very definitely by laboratory and by service tests which establish this material as one of great merit for certain types of concrete construction. It has also been shown that the admixture of oil is not detrimental to the tensile strength of mortar composed of 1 part of cement and 3 parts of sand when the oil added does not exceed 10 per cent of the weight of the cement used. The compressive strength of mortar and of concrete suffers slightly with the addition of oil, although when 10 per cent of oil is added the decrease in strength is not serious. Concrete mixed with oil requires a period of time about 50 per cent longer to set hard than does plain concrete, but the increase in strength is nearly as rapid in the oil-mixed material as in the plain concrete. Concrete and mortar containing oil admixtures are almost perfectly nonabsorbent of water, and so they are excellent materials to use in damp-proof construction. Under pressure, oil-mixed mortar is very efficient in resisting the permeation of water. Laboratory tests show that oil-mixed concrete is just as tough and stiff as plain concrete, and furthermore its elastic behavior within working limits of stress is identical with that of plain concrete. The bond or grip of oil concrete to steel reinforcement is much decreased when plain bars are used. Deformed bars, however, and wire mesh or expanded metal will reinforce this material with practically the same efficiency as in ordinary concrete.

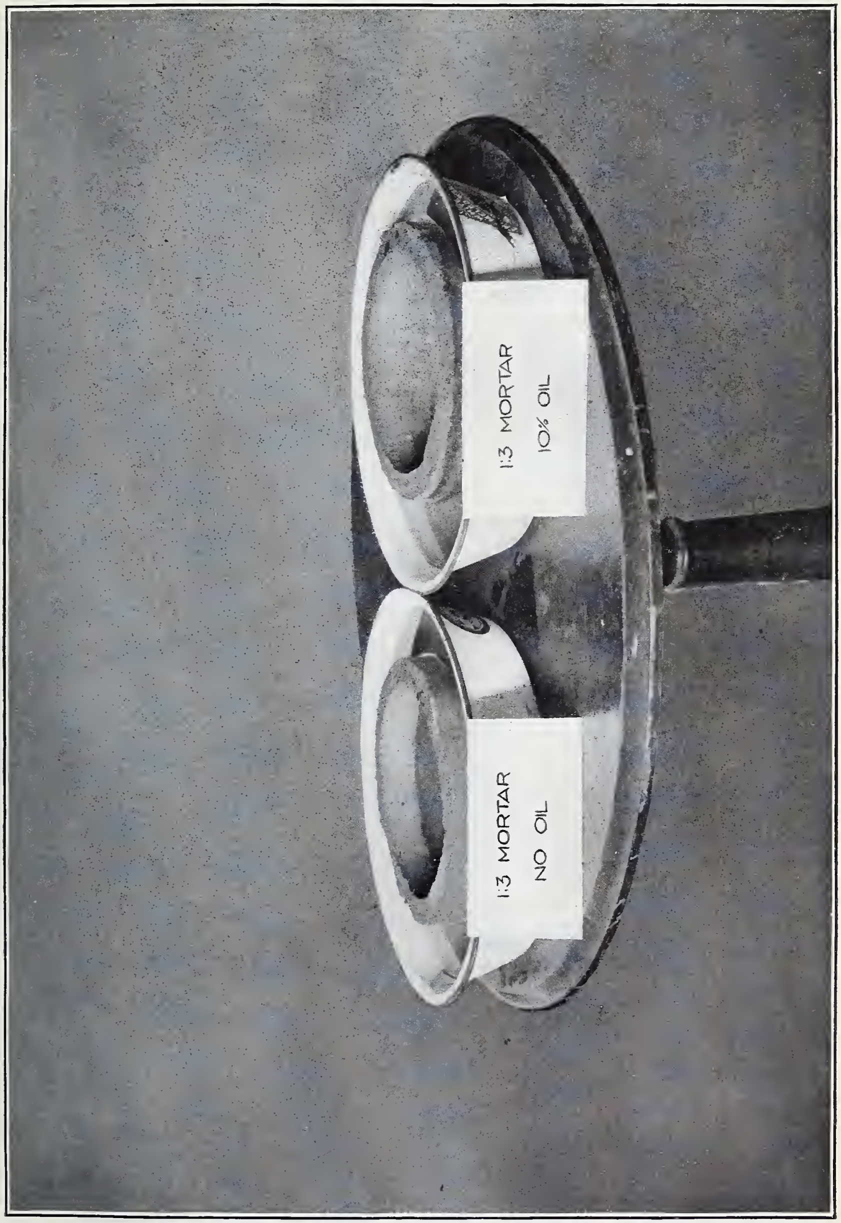
SERVICE TESTS.

Two bridge surfaces of oil-mixed concrete were laid during April and May, 1910. In the Borough of Richmond, New York City,



VAULTS IN THE UNITED STATES TREASURY DEPARTMENT.

VAULTS IN THE UNITED STATES TREASURY DEPARTMENT (DETAILED VIEW).



LABORATORY TEST OF OIL-MIXED MORTAR.

during May and June of the same year about 400 feet of street were laid with different kinds of aggregate. About 400 feet of street were surfaced in June, 1910, in the city of Washington. Likewise in the suburbs of Harrisburg, Pa., about one-half mile of roadway was laid with a 10 per cent oil mixture. Time alone will show the efficiency of this type of road surfacing under the different conditions of traffic to which it is being subjected.

Service tests of oil-mixed concrete used as a damp-proofing material have likewise been made. A vault 112 feet long by 18 feet wide in the United States Treasury Department was constructed in the fall of 1910. (Pls. I and II.) The side walls of this vault contain 10 per cent of oil based on the weight of cement in the mixture. The roof was constructed of ordinary reinforced concrete with about 3 inches of 10 per cent oil-mixed concrete placed on top. For months the roof of this vault was subjected to several feet head of water without showing any signs of leakage. Another vault in the north end of the Treasury, on account of leaking, has never been available for storing anything of value. Oil-mixed concrete was placed on the roof of this vault, and it is perfectly dry at the present time. Numerous floors in the sub-basement of the Treasury Department and a floor in the Office of Public Roads have been constructed with 10 per cent oil-mixed concrete and have remained absolutely free from dampness.

Several tanks constructed of oil-mixed concrete in the testing laboratory of the Office of Public Roads have remained absolutely water-tight since their completion over a year ago. One of these tanks was made of a mixture of concrete composed of 1 part of cement, 2 parts of sand, and 4 parts of stone, mixed with 10 per cent of oil based on the weight of cement in the mixture. It is used for storing concrete test specimens and is 14 feet long by 5 feet wide by 4½ feet deep. The bottom of this tank is 4 inches thick and is deposited on the cement floor of the laboratory. The sides are 6 inches in thickness and are reinforced with one-half inch deformed steel bars. A second tank was built very successfully merely by plastering oil-mixed Portland cement mortar against one-half inch mesh expanded metal. Although the sides and bottom of this tank are but 1 inch thick, it is absolutely water-tight against about 2 feet of head.

A very interesting experiment showing the nonabsorbent and non-permeable character of oil-mixed mortar when subjected to low pressure is incompletely shown in Plate III. Four mortar vessels, 8 inches in outside diameter, 2½ inches high, and about ½ inch thick, after hardening in moist air for one week, were immersed in water to a depth of about 2 inches. A mortar mixture of 1 part of cement to

3 parts of sand was used. Vessel No. 1 contained no oil in the mixture. About one minute after immersion a damp spot showed on the bottom. After one hour the whole vessel was wet even above the water level, since the water had climbed by capillarity. Within a few days water had penetrated the plain mortar vessel until the water level inside was the same as that outside. The remaining three vessels, made of 1:3 mortar and mixed with 5, 10, and 20 per cent of oil, respectively, have remained perfectly dry on the inside during immersion for one year.

All of these experiments have given very encouraging results and point to the use of oil-mixed mortars and concretes as a cheap and effective solution of the problem of waterproofing for a great many types of concrete construction.

MATERIALS USED.

As ordinarily made, concrete consists of a mixture of cement, sand, broken stone or gravel, and water. Oil-mixed concrete differs from ordinary concrete only in that oil is an additional ingredient in the mixture. It is important that the materials used in a concrete mixture be of the proper kind and be combined in the correct proportions for the work in hand.

CEMENT.

By far the best cement for use in oil-mixed concrete is Portland cement, not only because of its more uniform quality, but also because of its greater strength, which permits it to be mixed with a larger percentage of properly proportioned aggregate. For unimportant work it is usually safe to select a brand of cement of well-known reputation and use it without testing, although even for work of an insignificant character it will be wise to test the cement for its soundness or its liability to disintegrate.

A very quick test for soundness may be made by kneading some of the cement with enough water to form a paste of such consistency that it may be molded into a ball without crumbling. This ball, which should be about 1¼ inches in diameter, should be allowed to harden under a moistened cloth for 24 hours, after which it should be placed in a pan of cold water, and the water heated to the boiling point. If the cement ball shows no signs of cracking after boiling for three hours and remains hard and not disintegrated in any way, the indications are strongly in favor of the fitness of the sample.

On work of any importance, the cement should be carefully sampled and tested by a testing laboratory equipped for that purpose.

SAND.

The character of the sand used in a concrete mixture has a marked effect on the strength of the concrete. The sand should be clean and coarse. It should be reasonably free from clay or silt, since both of these materials tend to weaken a rich concrete mixture when present in large quantities. It is not advisable to permit more than 5 per cent of silt or clay in the sand. The sand grains should be coarse; that is, should be graded in size from one thirty-second up to one-eighth or one-fourth inch in diameter. Sand graded in size from small to large makes a denser and stronger mortar than sand of uniform size. Should fine sand be the only material available, it will be necessary to use an increased quantity of cement in order to obtain the same strength that would be obtained from the use of a coarser sand.

STONE.

The best rocks for concrete are, in general, the traps and granites, although some varieties of sandstone and limestone give very good results. Gravel which is clean makes an excellent material for use in concrete. The best results are usually obtained with stone graded in size from one-fourth inch up to $1\frac{1}{2}$ inches, but for reinforced work a maximum size of 1 inch is preferable. Whenever gravel is used, it should be screened through a one-fourth inch mesh screen and the finer particles should be later recombined with the coarser particles in the correct proportions. It is not a wise procedure to mix cement with the gravel as it comes from the bank, since the sand and larger pebbles are generally not proportioned correctly to obtain the densest and strongest concrete.

WATER.

The mixing water should be clean and free from all strong acids, alkalis, and vegetable matter.

OIL.

For oil-mixed concrete, petroleum residuum oils conforming to the specifications given below have been found to give good results in both laboratory and service tests.

SPECIFICATIONS FOR FLUID RESIDUAL PETROLEUM.

(1) The oil shall have a specific gravity of not less than 0.930 nor greater than 0.940 at a temperature of 25° C.

(2) It shall be soluble in carbon disulphide at air temperature to at least 99.9 per cent.

(3) It shall contain not less than 1.5 nor more than 2.5 per cent of bitumen insoluble in 86° B. paraffin naphtha.

(4) It shall yield not less than 2.5 nor more than 4 per cent of residual coke.

(5) When 240 cc. of the material is heated in an Engler viscosimeter to 50° C. and maintained at that temperature for at least 3 minutes, the first 100 cc. which flows out shall show a viscosity of not less than 40 nor more than 45.

(6) When 20 grams of the material is heated for 5 hours in a cylindrical tin dish 2½ inches in diameter by 1 inch in height, at a constant temperature of 163° C., the loss in weight shall not exceed 2 per cent.

METHOD OF MAKING.

For most purposes where damp-proofing is required 5 per cent of oil based on the weight of cement in the mixture is all that is necessary. A bag of cement weighs 94 pounds, and consequently, for each bag of cement used in the mixture, 4.7 pounds or about 2½ quarts of oil are required.

Let it be supposed that a batch of concrete requiring two bags of cement is to be mixed in the proportions of 1 part of cement to 2 parts of sand to 4 parts of broken stone or gravel, together with 5 per cent of oil. Four cubic feet of sand are first measured out in a bottomless box 12 inches deep and 2 feet on each side. On top of the sand is spread the cement and these materials are mixed together until they appear to be of uniform color. Water is then added to the mixture and the mass again mixed to a mortar of mushy consistency. Five quarts of oil are then measured out and added to the mortar, and the mass again turned until there is no trace of oil visible on the surface of the mortar. Particular care should be taken to continue the mixing until the oil is thoroughly incorporated in the mixture. The oil-mixed mortar is then combined with the stone or gravel previously moistened and the mass is again turned until all of the stone is thoroughly coated with the mortar and the mass is uniformly mixed throughout. Should only oil-mixed mortar be desired, the process is similar to that above described except that no stone is added.

In a machine mixer the cement, sand, and water are first mixed to a mortar when alternate batches of oil and stone are added until the required quantity of oil is mixed, and then the remainder of the stone is added and mixed.

MATERIALS REQUIRED FOR 1 CUBIC YARD.

The following table gives the proportions by parts and amounts required of cement, sand, stone, and oil to make a cubic yard of oil-mixed mortar and concrete.

TABLE NO. I.—*Quantities of materials required for 1 cubic yard of oil-mixed mortar and concrete.*

Proportions by parts.				Cement (barrels[1]).	Sand (cubic yards).	Stone or gravel (cubic yards).	Oil (gallons[2]).
Cement.	Sand.	Stone or gravel.	Oil (per cent).				
1	....	....	3	8.31	....	....	12.1
1	2	....	5	3.32	0.93	....	8.06
1	3	....	5 10	2.48	1.05	....	6.02 12.04
1	4	....	5 10	1.98	1.11	....	4.8 9.61
1	2	4	5	1.57	.44	0.88	3.81
1	2½	5	5 10	1.30	.46	.92	3.15 6.3
1	3	6	5 10	1.11	.47	.94	2.69 5.38

[1] One barrel of cement equals 4 bags.
[2] Oil weighs about 7¾ pounds per gallon.

USES.

All of the laboratory and service tests thus far made on oil-mixed mortars and concretes are indicative of a wide future usefulness for these materials, principally in damp-proof construction. There are many types of structures through which the permeation of moisture is ruinous to either the appearance or the efficiency of the construction, or is seriously detrimental to the health of either animal or human life. The efflorescence due to the leaching out and subsequent carbonization of the lime on the surface of a concrete wall might well be prevented by the incorporation of an agent capable of excluding all moisture. Again, the dampness of many cellars, with its danger to health, could have been prevented had the walls and floors been damp-proofed. The following types of structures might be damp-proofed at an exceedingly slight extra expense by the incorporation of a small amount of the proper kind of mineral oil residuum with the mortar or concrete used in construction: Basement floors, basement walls, watering troughs, cisterns, barns, silos, concrete blocks, roofs, stucco, and numerous important engineering constructions.

BASEMENT FLOORS.

There are many basement floors which are continuously damp, owing to the percolation of moisture from the underlying soil. Concrete and mortar as ordinarily made are neither perfectly nonabsorbent nor waterproof, so that ground water readily finds its way through to the basement and causes a very insanitary condition.

A floor which will remain perfectly dry may be constructed at a cost but very slightly higher than that of the ordinary basement floor by the incorporation of a petroleum residuum oil with the ordinary concrete mixture. The following method of construction, using an oil-cement mixture, is suggested as one which will prevent the permeation of moisture even from a very wet subsoil.

It will be well, if the underlying soil is very wet, to lay a 6-inch foundation of sand, cinders, broken stone, or gravel, compacting these materials well by tamping. In addition it will be of advantage to employ drain tiles in this porous foundation, leading them to a sewer if possible. On top of the foundation should be laid a 4-inch layer of concrete mixed in the proportions of 1 part of Portland cement, 2½ parts of sand, and 5 parts of broken stone or gravel. Before the concrete base has hardened, a top or wearing coat of mortar mixed in the proportions of 1 part of cement and 2 parts of sand or stone screenings and containing 5 per cent of oil (2½ quarts per bag of cement) should be laid. This top coat, because of its nonabsorbent character, will give perfect protection from underlying moisture, and moreover it will build a floor which will dry out very quickly after washing, since practically none of the washing water will be absorbed.

It might be thought that the addition of oil to the mortar-wearing coat would tend to make the surface slippery. Such, however, is not the case; nor is the appearance very much different from that of an ordinary cement floor. Should joints be provided for expansion and contraction, it will be necessary to fill them with a good bituminous filler to prevent the entrance of water.

Many cellar floors now made of Portland cement concrete are giving trouble owing to the permeating moisture. They are continually damp and, owing in part to the constant evaporation from their surface, they are cold. Such a condition may be remedied by the application of an oil-mixed mortar coat to the surface of the old floor. Before attempting to lay the new wearing surface, the old floor should be scrubbed thoroughly clean and should be made thoroughly wet. The bond between the old and the new work will be improved if the old surface be roughened with a stone hammer. A wash composed of 1 part of hydrochloric acid and 5 parts of water may be used to clean the surface. This will dissolve some of the cement from the old work, leaving the aggregate exposed. The acid solution should be left on not longer than half an hour, when it should be completely removed with clean water. The surface should then be brushed with a wire or stiff scrubbing brush to remove any particles of sand which may have become loosened because of the dissolving of the cement.

A mortar composed of 1 part of cement and 2 parts of sand and containing 5 per cent of oil will be sufficiently nonabsorbent for the new wearing coat. To strengthen the bond it will be well to apply a wash of grout, made by mixing cement with water to the consistency of cream, before laying the oil-mixed mortar coat. For the ordinary basement floor a 1-inch layer of mortar will prove of sufficient thickness. It will be necessary to keep the new mortar damp for at least one week in order that it may attain its proper strength.

CELLAR WALLS.

The entrance of moisture through the walls is another common source of damp basements. The water pressure in the soil adjacent to the wall is very seldom of great magnitude, so that a nonporous material and one that is at the same time impermeable under moderate pressures is the logical one to use for this type of construction.

A concrete mixture in the proportions of 1 part of cement, 2½ parts of sand, and 5 parts of gravel or broken stone, together with 10 per cent of oil based on the weight of cement in the mixture, should prove amply rich for most situations. A wall of these proportions, 12 inches thick and provided with a spread footing, will withstand a pressure of 6 feet of earth. When supported at the top by floor joists, a much thinner wall may be used with safety. A 6-inch wall 7 feet high may be used to withstand 6 feet of earth pressure. Generally speaking, such a thin wall should be reinforced by rods spaced about 2 feet apart in both directions. Smooth rods should not be used in oil-concrete mixtures, however, since the bond or adhesion of such rods is practically nil. Any of the many types of deformed bars, made especially for reinforcing, may be used with perfect results. Care should be taken that the earth is not filled in against the back of the wall for at least four weeks after pouring the concrete, unless the wall is braced on the inside by allowing the inner forms to remain in place.

Many basement walls now built of stone, brick, or concrete are giving trouble through leakage. The application of a plaster coat of oil-mixed mortar in the proportions of 1 part of cement to 2 parts of sand, together with 5 per cent of oil, and mixed with enough water to form a rather stiff mortar, will prove an efficient remedy for this trouble. The surface to which this mortar is to be applied should be roughened with a stone hammer, if the old wall is of concrete, or the mortar joints should be raked out to a depth of half an inch from brick or masonry walls. The acid wash previously described should be applied to cleanse the surface thoroughly, after which the loose particles must be removed with a wire brush or a stiff bristle brush. It will be impossible to obtain a water-tight coating if it is applied while water is seeping through the wall. It will be well to wait for the dry season, when the ground water is reduced to its lowest level, before attempting to waterproof by plastering. Should water appear to be coming through a well-defined crack in the wall, calking with oakum or cotton may be resorted to in order to stop the leakage until a plaster coat of oil-mixed mortar can be applied. It will be necessary to mix the mortar for plastering to a rather dry consistency, and it should be troweled hard in order to obtain a hard, dense waterproof surface. A wash of cement and water mixed to the consistency of thick cream and applied before the oil-mixed mortar coat will aid the new mortar in adhering to the old work. The old wall must be thoroughly wet before the new mortar coat is applied.

WATERING TROUGHS.

The use of oil-mixed concrete in the construction of watering troughs will be found to give excellent results in maintaining them in an absolutely water-tight condition.

For this purpose a mixture of 1 part of Portland cement, 2 parts of clean coarse sand, and 4 parts of gravel, ranging in size from $\frac{1}{4}$ inch to 1 inch is recommended. The mixture should likewise contain 10 per cent of oil based on the weight of cement and should be mixed to a jellylike consistency. It will be well to provide wire-mesh or steel-rod reinforcement for the bottom and walls. Care should be taken to puddle the concrete into place thoroughly and to trowel or spade the material adjacent to the molds. This flushes the mortar to the surface, making it smooth and dense, and rendering a finishing coat of plaster unnecessary. Should a very smooth surface be desired, an effective finish may be obtained by applying several paint coats of oil-mixed cement grout made as follows: Enough water should be mixed with cement to form a paste of soft, putty-like consistency. To this paste should be added 3 per cent of oil, based on the weight of dry cement in the mixture (a 10-quart bucket of dry cement requires about a pint of oil for this purpose), and the whole should be mixed until the oil is entirely combined with the other ingredients. The paste may now be thinned down with more water to the consistency of cream, after which it may be applied with a stiff brush to the previously dampened concrete. A second coat of this oil grout should be applied after the first coat has hardened. Care should be taken that it does not dry out too quickly by applying it to the dry concrete or exposing it to the direct rays of the sun. A tank built as described will be absolutely water-tight, and, furthermore, the waterproofing will have cost almost nothing in comparison with the costs of the other materials.

CISTERNS.

For waterproofing cisterns, oil-mixed concrete will prove of great benefit. It is absolutely necessary that cisterns which are buried in the ground be waterproofed to prevent contaminated ground water from seeping in, as well as to prevent the cistern water from escaping. Buried cisterns of rectangular shape should be reinforced to resist the earth pressure, which tends to bulge the side walls inward when the water runs low. The reinforcement should, therefore, be provided on the inside or tension side of the walls. The earth pressure will prevent the tank from cracking when it is full of water.

For cistern construction a mixture composed of 1 part of cement, 2 parts of sand, and 4 parts of gravel or broken stone, together with 10 per cent of oil, is effective. The inner faces of the cistern should be painted with an oil-mixed cement grout applied with a stiff brush and rubbed well into the face of the wall. Two coats of this grout, containing about 3 per cent of oil, should be used.

BARNS.

Barns constructed of concrete are gradually coming into use, because of their durability, cleanliness, resistance to fire, and economy. It is essential that the interior of these structures be kept free from moisture, and for this reason it is well to waterproof the concrete mixture entering the side walls and flooring. The side walls, unless waterproofed, have a tendency during a long beating rain to absorb and retain much moisture, and this moisture penetrates to the interior.

If oil in amount equal to 5 per cent of the weight of cement be mixed with the concrete used in the side walls, this damp condition of the interior becomes impossible, because the admixture of oil prevents the penetration of the moisture.

Barn floors should be waterproofed by the addition of oil as previously described. A damp-proof floor has the advantage of remaining dry and hence warmer, because there is no evaporation from the surface. It is likewise more sanitary than an ordinary concrete floor because of its nonabsorbent character.

CONCRETE BLOCKS.

The use of concrete blocks in the building trade is yearly increasing. Much criticism has been heaped on the building block, and in many cases the criticism has been just. It is recognized that many concrete-block houses are damp, owing to the fact that the walls are very porous, and absorb and retain much moisture after a heavy, beating rain. A building block generally need not be waterproofed against water pressure, but it should, however, be rendered proof against the permeation of water by absorption. The use of a small quantity of mineral oil in a concrete block renders it extremely nonabsorbent, so that even after a hard rain there is no danger from damp walls. In a 1:2:4 mixture, 5 per cent of oil is a sufficient quantity to waterproof properly against absorption.

ROOFS.

Portland cement mortar mixed with mineral oil and reinforced with steel-wire mesh may be advantageously used in the construction of roof slabs. These slabs could be assembled in place on the roof after they had attained sufficient hardness. Reinforced concrete tiles may also be advantageously made with Portland cement concrete mixed with a small percentage of mineral oil residuum.

STUCCO.

Portland cement stucco is widely used in the construction of many residences. This type of construction is economical, and, moreover, with it many beautiful effects are possible. The term "stucco" is given to the exterior finish coat, which may be applied to brick, stone, concrete, hollow tile, or frame construction. According to the finish desired and the kind of surface to be covered, the stucco is applied in two or three coats. The first, or scratch coat, should be mixed in the proportions of 1 part of Portland cement and 2 parts of clean, coarse sand, with enough water to form a good, stiff mortar. If 5 per cent of oil is added to this mixture, the scratch coat will be permanently waterproof. While this coat is still wet, it is roughened with a stick or trowel over the entire surface. The second coat, which may be of the same proportions, is plastered on after the first coat has set sufficiently to support it. The use of oil in this coat may be omitted if desired, and it may be given a rough-cast finish by using a trowel covered with burlap or carpet.

The second coat may also be applied by throwing it on with a wooden paddle. This produces a rough surface known as a slap-dash finish. A pebble-dash surface may be obtained from the use of pebbles one-fourth inch in diameter, mixed with cement in the proportions of 3:1, with a mixture that is quite wet. This mixture is thrown on the second coat while it is still soft and the result is a very pleasing surface. When a pebble-dash finish is used, the second coat, as well as the scratch coat, may be mixed with oil. In most constructions the second coat will be found superfluous, because a sufficiently thick coating is usually obtained from the first application of oil-mixed mortar.

When stucco is applied to stone or hollow tile, care should always be taken to have the surface well moistened or otherwise a great deal of water will be absorbed from the mortar coat, and so greatly weaken it and cause contraction cracks to form.

ENGINEERING CONSTRUCTIONS.

There are many important engineering constructions in which oil-mixed mortar or concrete may be advantageously employed. Among them may be mentioned aqueducts, buildings, burial vaults, boats, foundations, gutters, mausoleums, roofs, sewers, troughs, tanks, and wells. In some constructions a coat of oil-mixed mortar is effective, while in others oil-mixed concrete may be used throughout.

It is confidently believed that, if carefully prepared oil-mixed concrete is used in structures of any kind requiring damp-proofing—and in such structures careful work is a very important factor in the result—there will be no difficulty experienced from leakage and the structures will have been damp-proofed at very little extra expense.

APPENDIX.

PHYSICAL TESTS OF OIL-MIXED PORTLAND CEMENT CONCRETE.

In order to investigate the physical properties of oil-mixed Portland cement concrete, the following physical tests were conducted in the testing laboratory of the Office of Public Roads: (1) Tensile strength; (2) crushing strength; (3) time of setting; (4) toughness or resistance to impact; (5) stiffness or modulus of elasticity; (6) absorption; (7) permeability; and (8) bond tests.

The materials used consisted of Portland cement, river sand, crusher-run gneiss, and various kinds of petroleum residuum oils.

The mechanical analysis of the sand and stone used is given below:

TABLE No. II.—*Mechanical analysis of sand and stone*

Sand.		Stone.	
Sieve No.	Per cent retained.	Sieve No.	Per cent retained.
Inches.		*Inch.*	
1/4	3	3/4	28.4
1/8	11	1/2	66.3
10	17	1/4	92.1
20	42	1/8	98.4
30	66	....	....
40	87	....	....
50	93	....	....
80	96	....	....
100	99	....	....

There were 37 per cent of voids in the sand and 43 per cent in the stone.

The cement passed the specifications of the American Society for Testing Materials.

Various types of oils were used and these are described in the following table:

TABLE No. III.—*Analysis of oils used in oil-cement-concrete mixtures.*

Sample No.	4145	4146	4147	4149	4170	4923	4981	5053
Type	(1)	(1)	(1)	(1)	(2)	(1)	(1)	(1)
Character	(3)	(3)	(3)	(3)	(4)	(3)	(5)	(5)
Specific gravity at 25°/25°C.	0.924	0.910	0.926	0.923	....	0.945	0.893	0.924
Per cent of loss at 163° C., 5 hours, (20 grams)	6.86	12.56	7.98	7.02	18.38	1.35	27.17	3.70
Character of residue	(3)	(3)	(3)	(3)	(6)	(3)	(7)	(8)
Per cent of bitumen soluble in CS_2, air temperature	99.99	99.99	99.93	99.95	99.81	99.96	99.95	99.90
Per cent of organic matter insoluble	.01	.01	.07	.05	.13	.04	.02	.07
Per cent of inorganic matter insoluble	.00	.00	.00	.00	.06	.00	.03	.03
Total (per cent)	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Per cent of total bitumen insoluble in 86° B. paraffin naphtha	2.23	6.82	10.16	2.24	16.87	3.46	1.00	4.12
Fixed carbon	2.41	3.36	5.11	1.98	....	4.18	1.77	2.82
Specific viscosity, Engler, 50° C.	14.2	6.4	18.2	20.2	....	65.1	2.5	17.4

1 Fluid residual oil.
2 Cut-back oil asphalt.
3 Fluid, greasy.
4 Fluid, sticky.
5 Fluid, slightly sticky.
6 Semisolid, sticky.
7 Slightly granular, more viscous than original.
8 Fluid, granular in appearance.

TENSILE STRENGTH.

TABLE No. IV.—*Tensile strength (1:3 mortar, Ottawa sand).*

[Age in days.]

Per cent of oil.	Oil No. 4923.			Oil No. 5053.			Oil No. 4981.		
	7	28	180	7	28	180	7	28	180
	256	296	326	244	331	302	283	376	312
2½	299	400	449	297	353	298	259	327	323
5	287	316	372	313	334	325	268	341	321
10	252	331	360	304	371	330	264	329	319

The above results are plotted on figure 1. It will be noted that in general the specimens containing oil have a higher tensile strength than those without oil.

CRUSHING STRENGTH.

Specimens of mortar and concrete containing different percentages of various kinds of oils were molded 6 inches in diameter and 6 inches high. They were bedded in plaster of Paris or blotting paper and were crushed at a speed of 0.152 inch per minute. The following table gives the crushing strength obtained:

TABLE No. V.—*Tests of oil-mortar and oil-concrete cylinders.*

[Crushing strength is given in pounds per square inch. All 1:3 mortar (by weight) except 6c. to 18c., 6c. to 12c., 1:3:6 concrete; 13c. to 18c., 1:3:5 concrete (by volume).]

[NOTE.—Numbers in parentheses indicate number of specimens tested.]

Mark.	Per cent of oil.	Character of oil.	Stored in air.			Stored in water.		
			28 days.	6 months.	1 year.	28 days.	6 months.	1 year.
1	0	....	1,170(5)	1,350(2)	1,597(2)	2,135(6)	2,275(2)	2,308(2)
17	5	Fluid residual oil No. 4145	1,050(2)	830(2)	1,220(2)	1,715(2)	2,160(2)	2,240(2)
2	10	do	790(1)	....	....	1,320(1)	....	....
22	15	do	895(2)	780(2)	880(2)	1,290(2)	1,615(2)	1,700(2)
27	20	do	775(2)	910(2)	1,125(2)	1,020(2)	1,420(2)	1,425(2)
18	5	Fluid residual oil No. 4146	915(2)	....	1,110(2)	1,770(2)	....	2,560(2)
3	10	do	830(1)	....	....	2,400(2)	....	....
23	15	do	1,215(2)	1,275(2)	1,670(2)	1,775(2)	2,410(2)	2,475(2)
28	20	do	935(2)	1,295(2)	1,380(2)	1,345(2)	1,640(2)	1,780(2)
19	5	Fluid residual oil No. 4147	1,405(2)	1,155(2)	1,715(2)	1,995(2)	2,475(2)	2,700(2)
4	10	do	1,070(1)	....	....	1,720(1)	....	....
24	15	do	975(2)	1,085(2)	1,435(1)	1,670(2)	2,350(2)	2,250(1)
29	20	do	795(2)	1,055(2)	1,310(2)	1,400(2)	2,010(2)	1,895(2)
21	5	Fluid residual oil No. 4149	1,305(2)	1,105(2)	1,395(2)	2,220(2)	2,655(2)	2,450(1)
6	10	do	1,170(1)	....	....	1,750(1)	....	....
26	15	do	1,440(2)	1,395(2)	1,330(2)	1,895(2)	2,215(2)	2,320(2)
31	20	do	925(2)	1,085(2)	1,135(2)	1,230(2)	1,475(2)	1,530(2)
7	5	Cut-back oil asphalt No. 4170	1,010(2)	940(2)	1,315(2)	1,760(2)	2,065(2)	2,345(1)
8	10	do	980(2)	1,005(2)	1,510(2)	1,680(2)	1,825(2)	2,200(1)
9	15	do	1,055(2)	1,170(2)	1,555(2)	1,265(2)	1,365(2)	1,685(1)
10	20	do	890(2)	1,220(2)	1,325(2)	1,175(2)	1,340(2)	1,375(1)
6c	0	....	1,020(3)	980(2)	1,090(3)	1,370(2)	1,955(2)	2,170(3)
7c	2½	Fluid residual oil No. 4923	750(2)	915(2)	1,165(2)	1,253(3)	1,715(2)	1,580(3)
8c	5	do	711(2)	975(2)	1,015(2)	1,142(2)	1,690(2)	1,835(2)
9c	10	do	656(2)	755(2)	850(1)	961(3)	1,400(2)	1,440(3)
10c	15	do	542(2)	670(2)	675(2)	750(2)	995(2)	1,145(3)
12c	25	do	605(3)	678(2)	....	620(3)	1,030(2)	1,120(2)
13c	0	....	920(2)	998(3)	1,010(1)	1,342(3)	1,705(3)	1,890(3)
14c	2½	Fluid residual oil No. 4923	727(2)	945(3)	995(3)	1,250(2)	1,830(2)	2,410(3)
15c	5	do	720(2)	822(2)	912(3)	1,082(2)	1,626(2)	1,715(3)
16c	10	do	698(2)	965(2)	975(3)	1,040(2)	1,406(2)	1,490(3)
17c	15	do	693(2)	828(2)	888(3)	1,040(2)	1,380(2)	1,382(3)
18c	20	do	572(2)	639(2)	772(2)	904(2)	1,116(2)	1,230(3)

The foregoing results are plotted on figures 2 and 3. It will be noted that the crushing strength is decreased by the addition of oil, but that the decrease is not serious when the amount of oil does not exceed 10 per cent. It will also be noted that oil-mixed cement con-

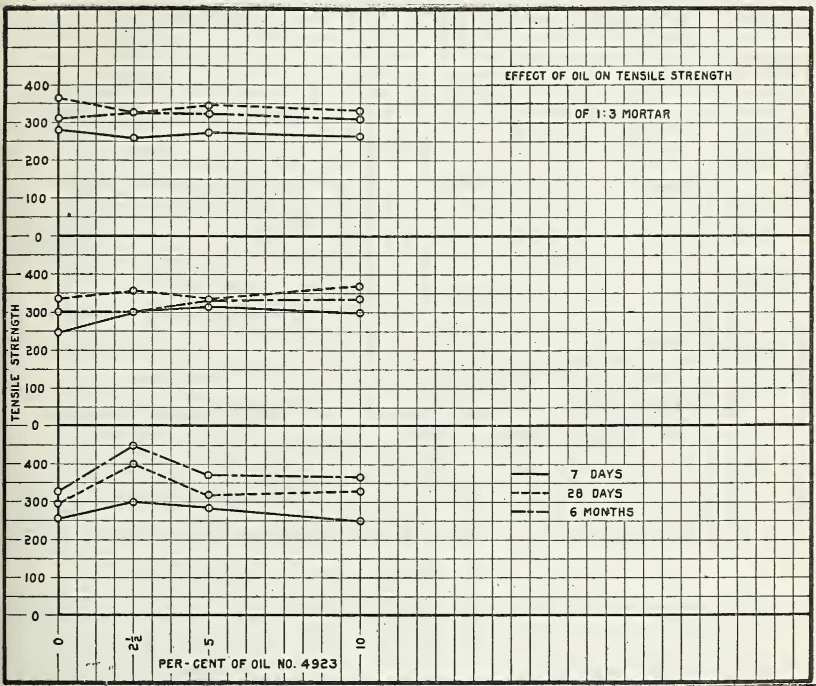


FIG. 1.—Effect of oil on tensile strength.

crete gains in strength with time in the same manner as untreated concrete—a fact which indicates that the addition of oil to the mixture in small amounts has no disintegrating effect on the cement.

TIME OF SETTING OF PORTLAND CEMENT.

TABLE No. VI.—*Effect of oil on time of setting.*

Oil No. 4923.		
Per cent of oil.	Initial set.	Final set.
	H. m.	*H. m.*
0	1 18	3 43
2½	1 31	4 56
5	1 57	5 27
10	2 27	5 57

The time of setting is delayed with the addition of oil, as shown by the above tests, which are plotted on figure 4. These results were obtained with the Gillmore needles on specimens subjected to identical conditions while hardening. Five per cent of oil delays the initial set by 50 per cent and the final set by 47 per cent.

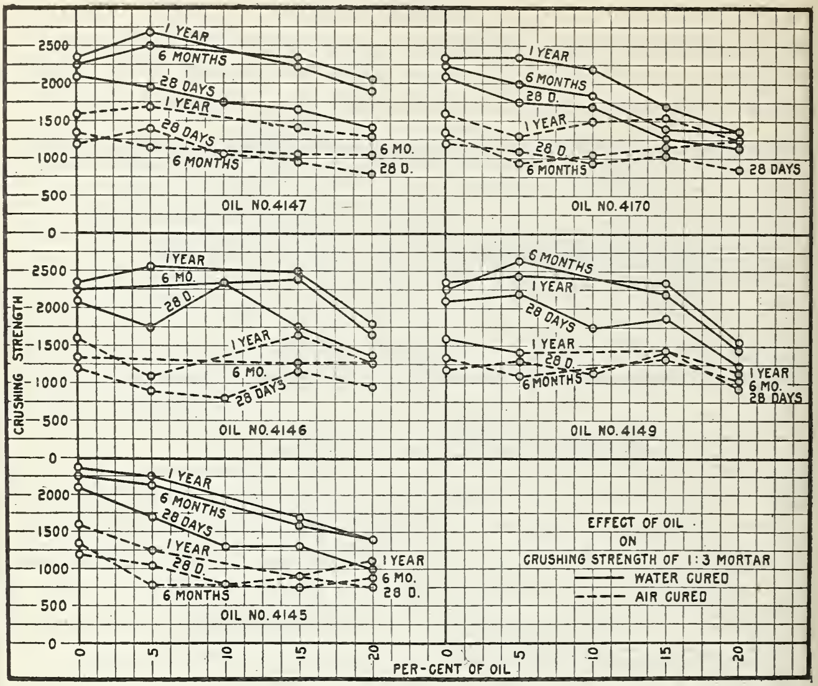


FIG. 2.—Effect of oil on crushing strength of 1 : 3 mortar.

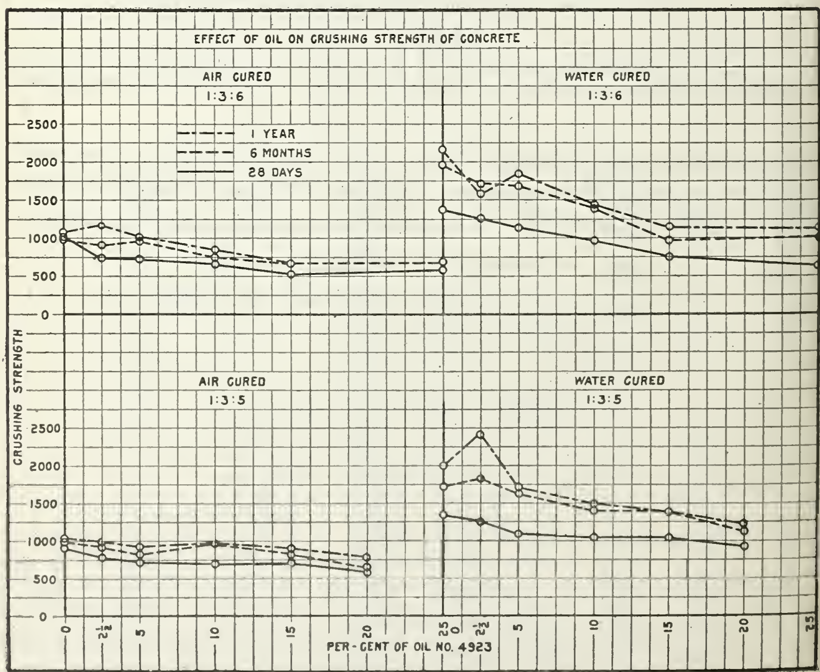


FIG. 3.—Effect of oil on crushing strength of concrete.

TOUGHNESS OR RESISTANCE TO IMPACT.

The toughness or resistance to impact was tested on the Page impact machine under the blows of a 10-kilogram hammer falling on a 5-kilogram plunger from successively increasing heights of 1 centimeter. The height of the last blow causing failure corresponds to the number of blows. The end of the plunger in contact with the specimen is spherical in shape, with a radius of 3 centimeters. Specimens 6 inches in diameter and 6 inches high were tested after first bedding them in plaster of Paris before mounting on the anvil of the

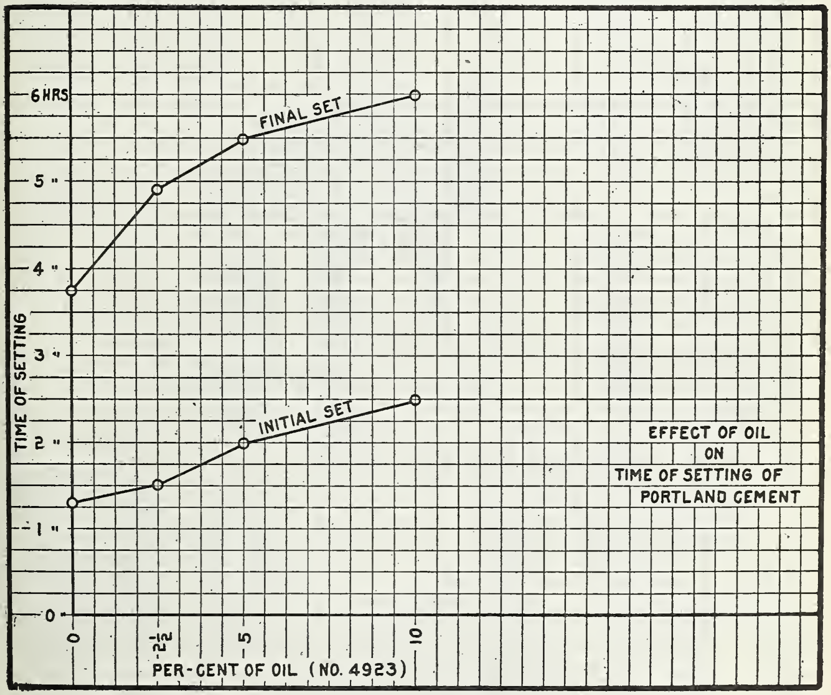


Fig. 4.—Effect of oil on time of setting of Portland cement.

machine. The following results show that the toughness of concrete is very little influenced by the addition of a small amount of oil to the mixture:

Table No. VII.—*Number of blows required to produce failure.*

Per cent of oil No. 4923.	1:3:5 concrete.		1:3:6 concrete.	
	Air-cured.	Water-cured.	Air-cured.	Water-cured.
0	18	15	15	21
2½	15	33	14	18
5	23	20	15	20
10	13	20	12	21
15	14	20	13	16

A view of the impact machine with a specimen under test is shown in Plate V.

STIFFNESS OR MODULUS OF ELASTICITY.

For testing the effect of oil on the stiffness of concrete specimens 8 inches in diameter and 16 inches high were made. The deformations under various loads were measured with a double micrometer screw compressometer of the type described by J. M. Porter in the Proceedings of the American Society for Testing Materials, Volume

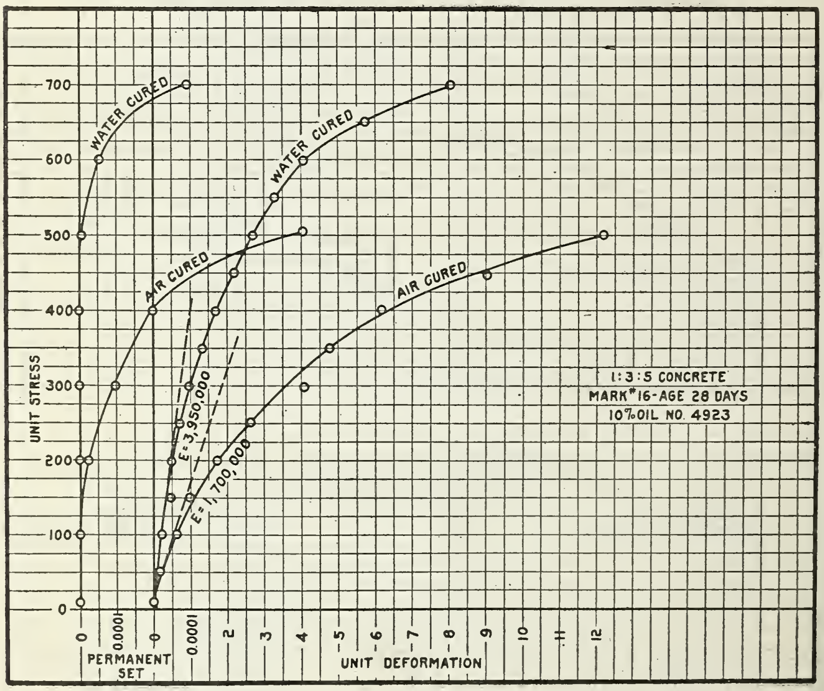
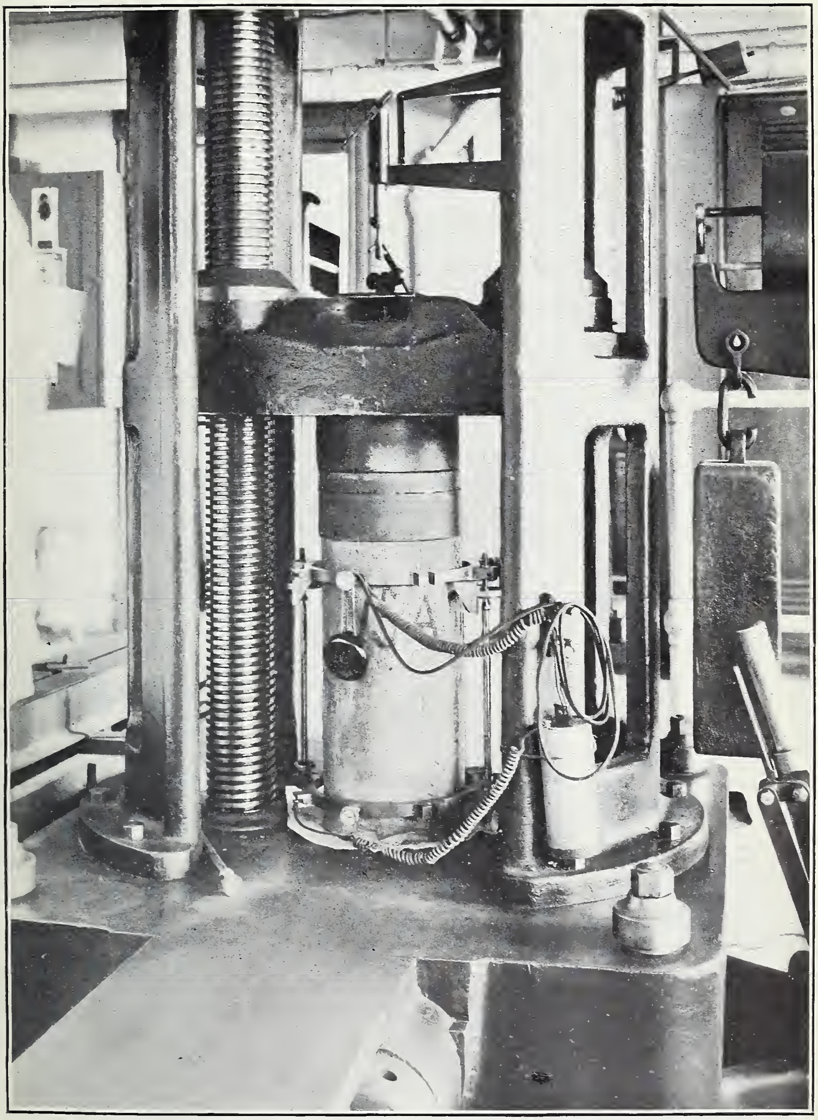
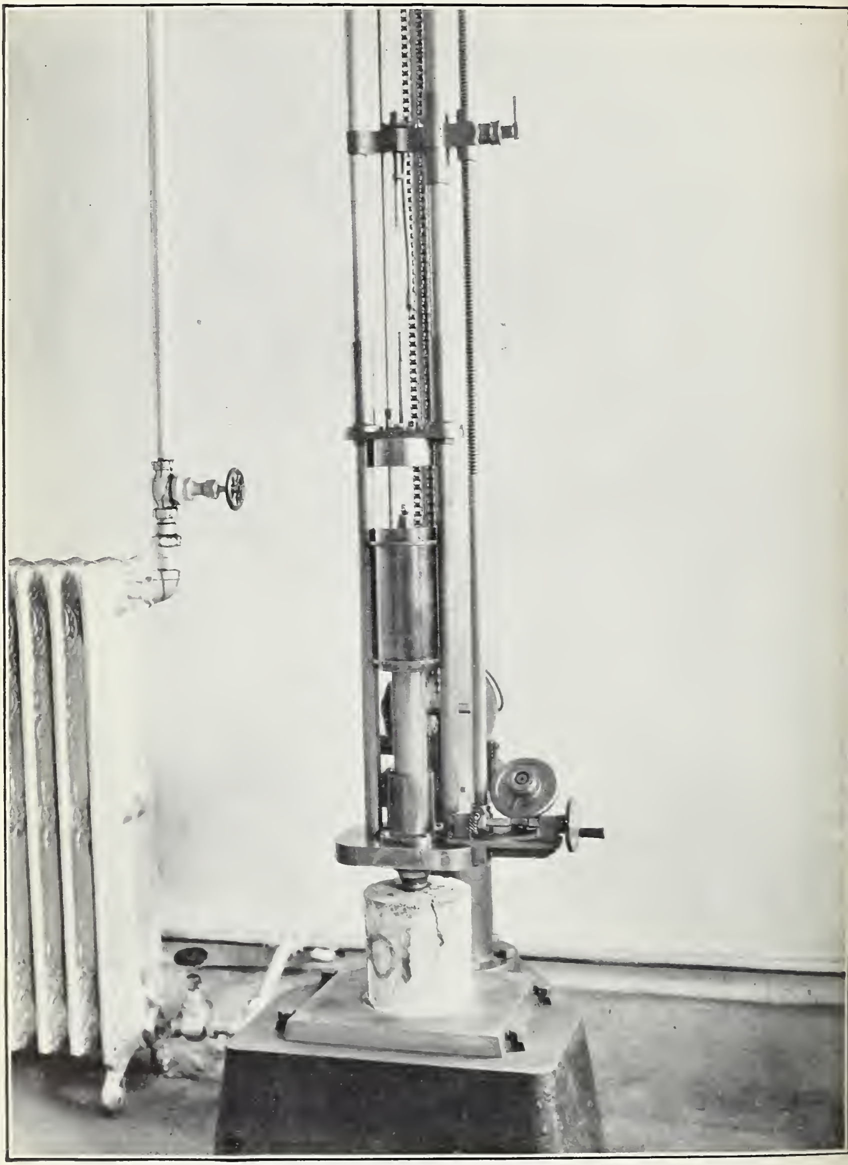


FIG. 5.—Modulus of elasticity and permanent set.

X, 1910. Loads were applied in 2,500 and 5,000 pound increments and were released to 500 pounds after each increment of 5,000 pounds, and deformation readings were taken for permanent set. Typical stress deformation and permanent set curves are shown in figure 5. In all cases the initial modulus of elasticity was obtained from the slope of the stress-strain curve at its origin. A view of a specimen mounted in the testing machine with compressometer attached is shown in Plate IV.



TESTING THE STRENGTH AND ELASTICITY OF OIL-MIXED CONCRETE.



IMPACT TEST ON OIL-MIXED CONCRETE.

TABLE No. VIII.—*Initial modulus of elasticity (age 28 days).*

Per cent of oil No. 4923.	1:3:5 concrete.		1:3:6 concrete.	
	Air-cured.	Water-cured.	Air-cured.	Water-cured.
0	1,300,000	2,550,000	1,300,000	2,200,000
2½	1,350,000	2,700,000	1,000,000	2,400,000
5	1,250,000	2,350,000	850,000	1,900,000
10	1,700,000	3,950,000	1,150,000	1,900,000
15	1,300,000	2,500,000	730,000	2,050,000

The above results show that oil has little effect on the stiffness of concrete. The increased value of the modulus of elasticity of the water-cured over the air-cured specimens is as marked in the oil-mixed as in the plain specimens. Tests at one year, although not here recorded, show that oil-mixed concrete gains as much in stiffness with age as the plain concrete does.

ABSORPTION.

The resistance of concrete to the penetration of moisture is measured by its absorptive qualities. To test the absorption of oil-mixed concrete compared with plain concrete, cylindrical specimens 6 inches in diameter and 6 inches high were dried to constant weight in an oven, after being cured for 15 days in air. They were then immersed in water and weighed from time to time. The results of these tests are plotted on figure 6. It will be seen that the oil greatly decreases the percentage of absorption; the cylinder containing 10 per cent of oil absorbed 1.7 per cent of water, based on the dry weight, while the cylinder containing no oil absorbed 6.25 per cent.

PERMEABILITY.

To investigate permeability, specimens 3 inches in thickness and 6 inches in diameter were molded with a surrounding ring of 1:1 mortar. Before testing, the top and bottom surfaces were chipped off in order to eliminate the waterproofing effect of the rich surface layers. Plain 1:3 mortar at the age of 28 days under 30 pounds' pressure became damp after half an hour. Under 40 pounds' pressure the leakage amounted to 146 cubic centimeters after 24 hours' application. Specimens containing 5 and 10 per cent of oil No. 4923 remained perfectly tight under 40 pounds' pressure.

All permeability specimens made of gravel concrete and containing admixtures of oil have remained perfectly tight under 40 pounds' pressure per square inch. Some of the plain gravel specimens made to compare with the oil-mixed specimens leaked, while others remained tight. Broken-stone concrete made with a very inferior grade of crushed gneiss is not perfectly water-tight under pressure at early periods. After storing for one year, however, even this inferior grade of oil-mixed concrete gives indications of being much less permeable than plain concrete.

BOND TESTS.

To determine the adhesion of oil-mixed concrete to steel reinforcement, bond tests were made on specimens mixed in the proportions of 1:2:4 and containing various percentages of oil. Rods 12 inches long were embedded in the center of cylinders 8 inches in diameter and 8 inches long. The test consisted in pushing the rods through

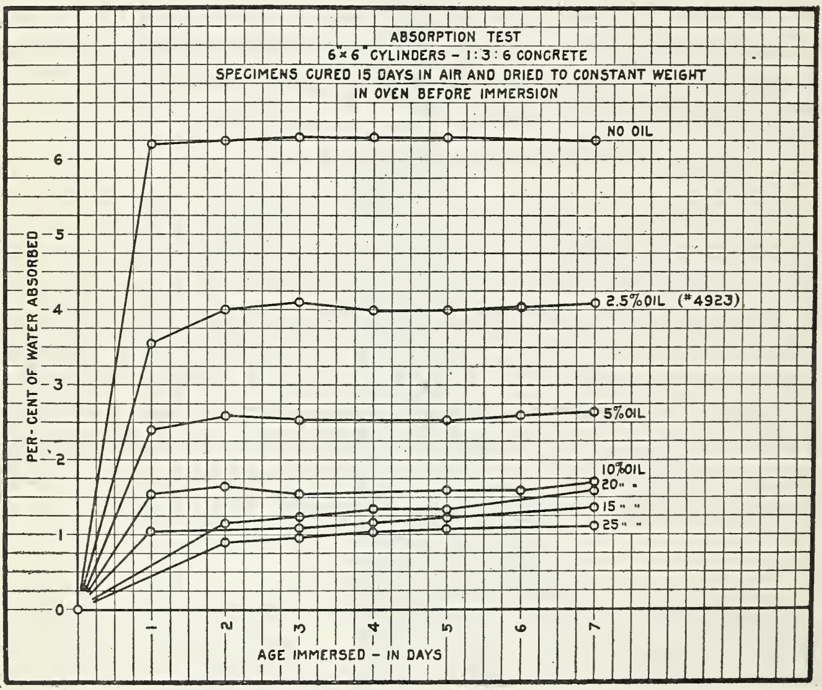


FIG. 6.—Absorption test.

the concrete, and the point of failure was taken at the drop of the scale beam.

Two kinds of bars were used—plain and deformed. All specimens were tested at 28 days, and the results are plotted on figure 7, The bond strength is decreased, and the decrease depends directly on the quantity of oil in the mixture. It is evident that the bond between plain bars and concrete is so seriously affected by the mixture of oil that it would be inadvisable to use such a combination. The bond of deformed bars is not so seriously affected but is somewhat decreased by the oil admixture.

SUMMARY OF CONCLUSIONS.

The following conclusions as to the effect of the oils used in cement and concrete may be drawn from the foregoing investigations:

(1) The *tensile strength* of 1:3 oil-mixed mortar is very little different from that of plain mortar, and shows a substantial gain in strength at 28 days and 6 months over that at 7 days.

(2) The *times of initial and final set* are delayed by the addition of oil; 5 per cent of oil increases the time of initial set by 50 per cent and the time of final set by 47 per cent.

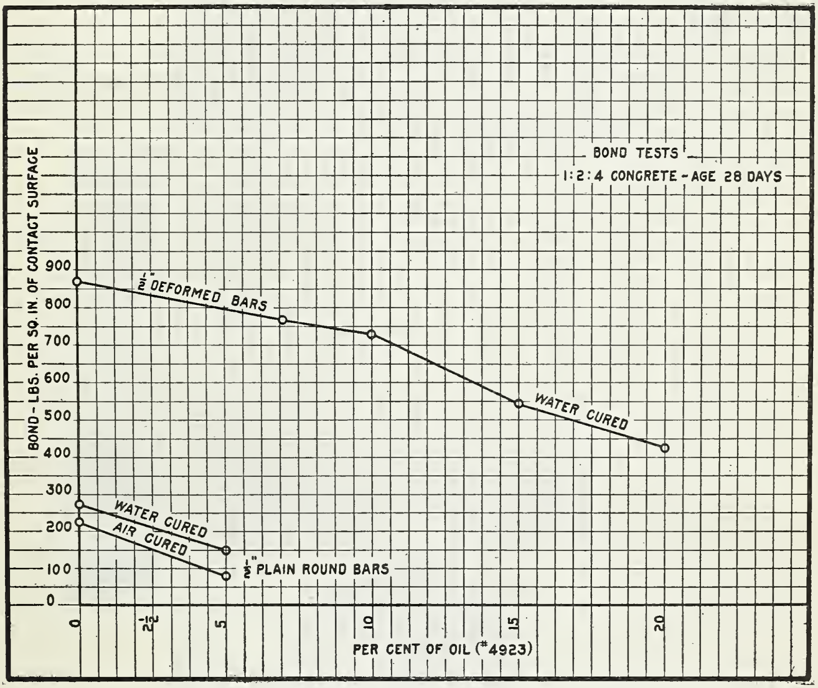


FIG. 7.—Bond tests.

(3) The *crushing strength* of mortar and concrete is decreased by the addition of oil to the mix. Concrete with 10 per cent of oil has 75 per cent of the strength of plain concrete at 28 days. At the age of 1 year the crushing strength of 1:3 mortar suffers but little with the addition of oil in amounts up to 10 per cent.

(4) The *toughness* or resistance to impact is but slightly affected by the addition of oil in amounts up to about 10 per cent.

(5) The *stiffness* of oil-mixed concrete appears to be but little different from that of plain concrete.

(6) *Elasticity.*—Results of tests for permanent deformation indicate that no definite law is followed by oil-mixed concrete.

(7) *Absorption.*—Oil-mixed mortar and concrete containing 10 per cent of oil have very little absorption and under low pressures both are waterproof.

(8) *Permeability.*—Oil-mixed mortar containing 10 per cent of oil is absolutely water-tight under pressures as high as 40 pounds per square inch. Tests indicate that oil-mixed mortar is effective as a waterproofing agent under low pressures when plastered on either side of porous concrete.

(9) The *bond tests* show the inadvisability of using plain bar reinforcement with oil-concrete mixtures. The bond of deformed bars is not seriously weakened by the addition of oil in amounts up to 10 per cent.

NOTE.—*A public patent has been granted for mixing oil with Portland cement concrete and hydraulic cements giving an alkaline reaction, and therefore anyone is at liberty to use this process without the payment of royalties.*

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